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Modeling the Logistics of Construction Materials through the Petri Net Techniques

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Abstract

Many studies have shown that the careful planning of construction logistics can result in significant saving. However, despite attempts to improve the logistics of construction materials, the purchase, delivery, storage and movement of materials are still conducted in a rather unstructured manner. In this paper, construction logistics are modeled and analyzed using Petri Net (PN) techniques. The background of the PN concept and its properties are first introduced, followed by an outline the PN model for construction logistics. The likely effects before and after the introduction of the Just-In-Time (JIT) concept are then examined. The findings suggest that significant time and cost savings can be made by incorporating the JIT concept.

Keywords: *Just-in-time, Petri Net, construction logistics, material planning*

Introduction

Construction projects are complex and resource intensive, and there is a need to adequately plan the purchase, delivery, storage and movement of construction materials to avoid unnecessarily obstructing the workflow (Caron *et al*, 1998). In a recent study, however, Agapiou *et al* (1998a) recorded 251 "incidents" relating to material deliveries, with approximately 45% leading to additional costs for the parties concerned. This, and other similar work has led to the conclusion that logistics management is generally quite poor in the construction supply chain, with logistics costs amounting to as much as 27% of the purchase price - 60% being caused on the construction site itself (Wegelius-Lehtonen, 2001). It is suggested, therefore, that savings in the construction industry will invariably be realized should the logistics on site be improved (Agapiou *et al*, 1998b), with studies conducted by the Danish Building Research Institute (SBI) indicating this to be potentially around 5% of construction costs.

Of course, logistics is not solely concerned with purchasing the required amount of materials at the lowest price, but it also involves the delivery of materials to the designated location at the appropriate time for installation (Canadine, 1996). One approach to this is the "Just-In-Time" (JIT) philosophy, which requires materials or components to be produced and delivered just before they are assembled into finished goods so as to avoid unnecessary inventories (Low and Mok, 1999; Low and Choong, 2001).

The successful application of JIT is clearly likely to be most beneficial for projects in a confined site especially where massive prefabricated components are involved, and there are many successful examples in the manufacturing industry (e.g. Lim and Low, 1992; Low and Chan, 1997). Despite this, the JIT concept has never been widely adopted in construction. One problem is that, ideally, an exact number of components should be delivered to the site without keeping any buffer stock. This is hard, if not impossible, to implement strictly in construction practice, as any miscalculation will result in excessive idle times for plant and human resources (Low and Mok, 1999). What seems to be needed is a way of improving the JIT concept by allowing some buffer stocks on site. Knowing that excessive stockpiling can affect efficiency, there is a need to identify the optimal number of buffer stocks for a project.

To date, many computer models have been developed to simulate and analyze construction processes. Of these, perhaps the most easily understood graphical and analytical tool is the Petri Net (PN) (Li *et al*, 1999). PN techniques allow researchers to unveil the structural properties of a system (Al-Jaar and Desrochers, 1900; Murata, 1989); evaluate performance (Lin and Lee, 1993); and simulate the processes involved (Balbo and Chiola, 1989). This paper describes a model for simulating the logistics of construction materials using the PN techniques and an example is used to illustrate the effects of the JIT philosophy in construction logistics.

Petri Nets

The origin of PN can be traced back to Carl Adam Petri's 1962 PhD thesis on the topic. Since then, it has been accepted as a formal analytical tool for a variety of systems *viz*. concurrent, distributed, asynchronous, parallel, deterministic and non-deterministic.

PN is a graphical and mathematical modeling tool for use in performing static and dynamic analyses of the processes involved in existing or new systems. One important characteristic is that the same model can be used to determine the qualitative properties of a system as well as its quantitative properties. As a result, PN techniques have been applied to various disciplines such as business, engineering, manufacturing, chemistry, and even judicial system. In construction, they have been utilized in analyzing concrete production plant and structural steel erection processes (Sawhney *et al*, 1999); modeling the procurement process (Li *et al*, 1999); and as a formalism to assist process improvement (Li, 1998).

The basic structure of PN includes (i) a finite set of "places"; (ii) a finite set of "transitions"; (iii) a finite set of "arcs"; and (iv) a set of "tokens" that define the initial markings. The signs commonly used for denoting the "place", "transition", "arc" and "token" are illustrated in Table 1. In essence, the "arcs" define the input and output functions which govern the flow of tokens from "places" to "transitions" and from "transitions" to "places" respectively.

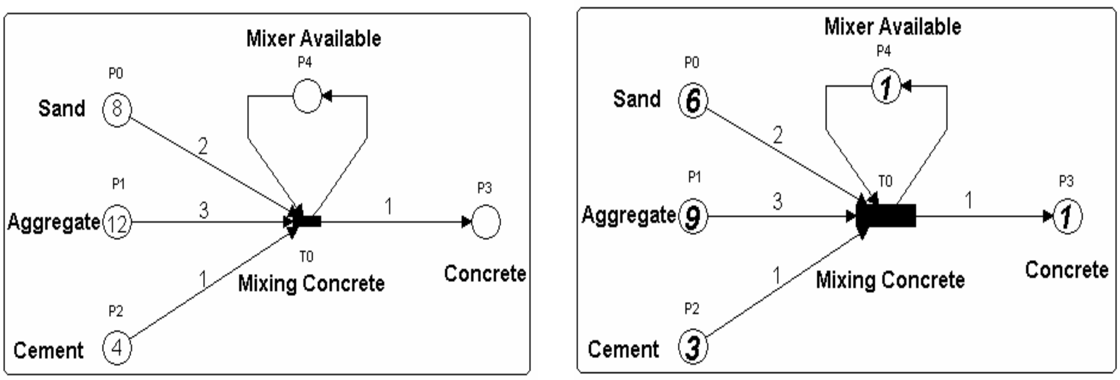
In PN modeling, the “place” can be regarded as a condition while the ‘transition’ is equivalent to an event. Therefore, a “transition” could have a number of input and output places representing the pre-conditions and post-conditions of the event respectively. The presence of a “token” in a “place” (being interpreted as *k* data items) indicates that resources are available (Nakashima and Gupta, 2003).

Table 1: Petri net modeling elements

Sign of Each Element		***Description***
Place	○	Element representing a node where a resource or input waits
Transition	▬	Element representing a task or an activity
Token	●	Element representing a resource or an input signal
Arc	⟶	Element that connect places and transitions

In order to simulate the dynamic behavior of a system, a state or marking in the PN has to be changed according to the following transition (firing) rules:

- a “transition” (*t*) is said to be enabled if each “input place” (*p*) of (*t*) is marked with at least $w(p,t)$ amount of “tokens”; where $w(p,t)$ is the weight of the “arc” from (*p*) to (*t*);
- an enabled “transition” may or may not fire, as it would depend on whether or not the event has actually taken place; and
- a firing of an enabled “transition” (*t*) removes $w(p,t)$ amount of “tokens” from each “input place” (*p*) of (*t*), and adds $w(t,p)$ amount of “tokens” to each “output place” (*p*) of (*t*); where $w(t,p)$ is the weight of the “arc” from (*t*) to (*p*).



(a) *(b)*

Figure 1: An example showing the basic concept of transition firing in the Petri Nets

The dynamic analysis in a PN is performed through the concept of transition firing or enabling. Figure 1(a) illustrates the initial state of a simple PN related to the production of concrete. In this example, it is assumed that the concrete is produced by mixing cement, sand, and aggregate together in a mixer. The “places” P_0, P_1, P_2 refer to sand, aggregate and cement respectively, with all being “input places”. P_3 refers to concrete which is an “output place”. The “arcs” connecting the “input places” with the “transition” have weights of 2, 3, and 1 respectively. This means that the transition will fire when at least two “tokens” of sands, three “tokens” of aggregate, one “token” of cement and one "token" of mixer are available in each of the "input places" and that when the "transition" has fired those "tokens" will be transferred by "transition" (T_0) and receive one "token" of concrete at P_3. The mixer is available at both "input place" and "output place" for the "transition". Therefore, after the raw materials are mixed, the mixer is available for the "input place" once again.

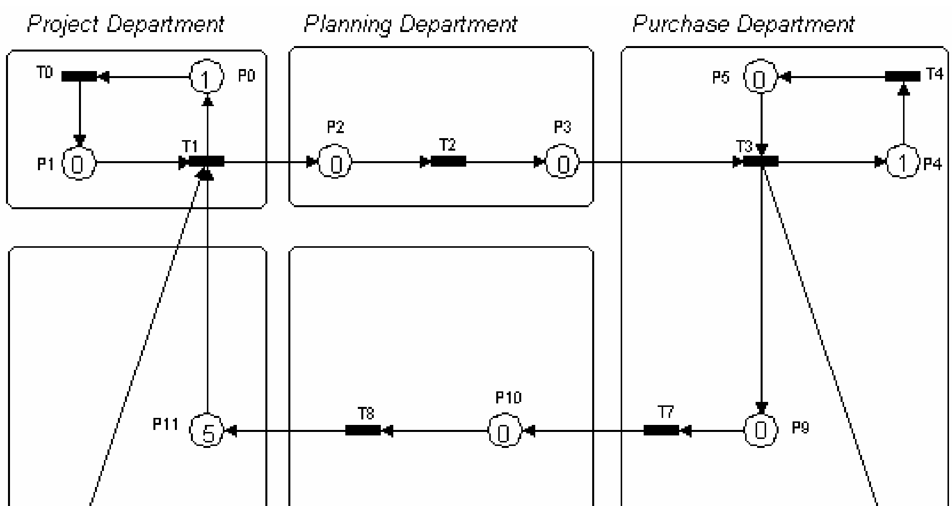
Figure 1(b) represents the state of adding one unit of concrete after two units of sand, three units of aggregate and one unit of cement have been mixed. In this state the firing "transition" is shown with an enlarged size and the number of "token" after "transition" are shown in bold and italic. The dynamic processing of the PN is performed according to the transition rules mentioned above. Thus the concept of transition firing superimposes the dynamic behavior of a process under consideration onto its graphical model.

Modeling Construction Logistics By Petri Nets

The PN concept can be applied to construction logistics. Consider the following scenario for a construction project:

- two independent materials, i.e. Material A and Material B, are required for the construction process;
- five entities are involved in the construction logistics process, and they are the Project Department, Planning Department, Purchase Department, suppliers and on-site inventory personnel; and
- all the weights of "arcs" in the PN model are defaulted as 1.

The PN model of the above construction logistics process as simulated by PetriTools™ (Richard, 1996) is shown in Figure 2. The arrows denote the flow of the "tokens". During construction, the material demand and the inventory situation (assuming that the initial storage of Materials A and B is 4 and 5 units respectively) are transferred to T_1 for the preparation of the demand report. This demand report is then delivered to the Planning Department for demand plan generation. When the demand plan is completed by the Planning Department (through the firing of T_2), it is then passed on to the Purchasing Department for processing. By referring to the market conditions at the time, the Purchasing Department selects a supplier and places an order (T_3). The process of supplier selection could be time consuming, but would save cost should an appropriate supplier be selected. Having completed its task, the Purchasing Department transfers the order to the supplier (T_5 and T_7), and material production begins. Eventually, the materials are delivered to the site (T_6 and T_7). As the construction project continues, a new demand plan is made ready for transmitting to the relevant parties and a new logistics circle begins.



T_0: constructing	*P_0: available construction capacity*
T_1: generating material demand	*P_1: construction processing*
T_2: making material plan	*P_2: demand report*
T_3: material ordering	*P_3: material demand plan*
T_4: deal with market information	*P_4: available market information*
T_5: ordering of Material A	*P_5: useful market information*
T_6: delivery of Material A	*P_6: number of suppliers for Material A*
T_7: ordering of Material B	*P_7: prepare for Material A*
T_8: delivery of Material B	*P_8: available Material A*
	P_9: number of suppliers for Material B
	P_{10}: prepare for Material B
	P_{11}: available Material B

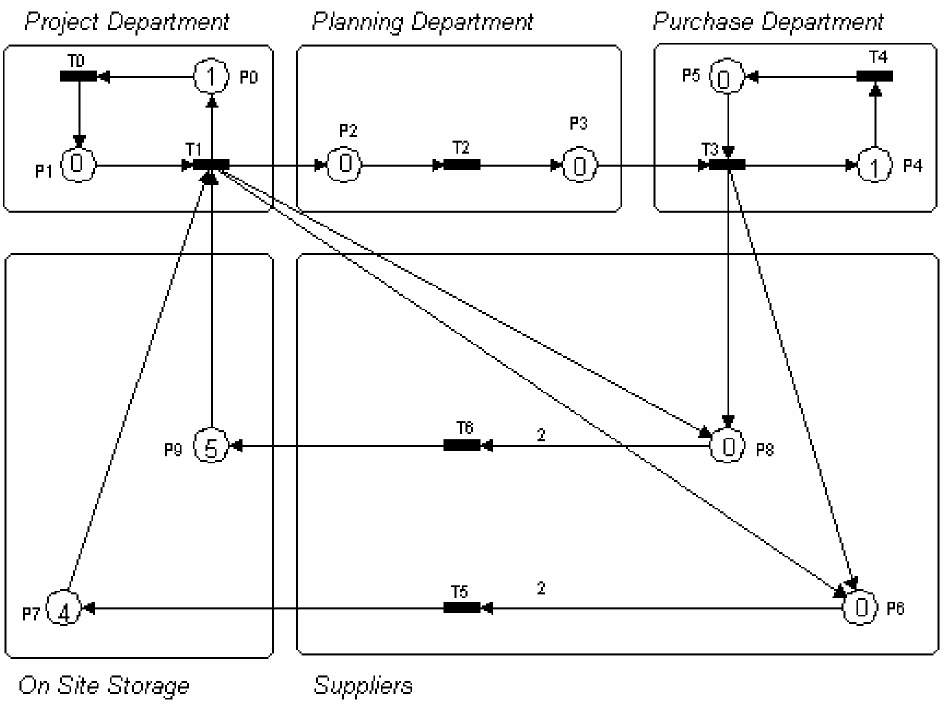
Figure 2: A simulation of the construction logistics process

In the above model, the concept of JIT has not been introduced to the ordering and delivery of materials. When the demand plan goes to the Purchasing Department, there are two tasks for this Department to carry out: (i) to select a supplier according to market information (which is the most important task), and (ii) to place an order. One bottleneck in the above process lies with the Purchasing Department, as the selection of an appropriate supplier and associated negotiation process could take time. Furthermore, it could take excessive time to prepare and deliver the materials to the site even if an order is placed in advance. If the contractor wishes to ensure smooth progress on site, a demand plan must be prepared and an order placed long before the materials are really required. Naturally, this could give rise to excessive on-site or off-site storage costs.

Incorporating The Just-In-Time Concept

The JIT concept can be incorporated to improve the logistics of material supply. Figure 3 shows the revised PN model. In the new model, the following assumptions are added:

- a long and stable relationship exist between the construction company and its suppliers; and
- the suppliers have direct access to information on project progress and material demand from the Project Department.



T_0: constructing
T_1: generating material demand
T_2: making material plan
T_3: material ordering
T_4: deal with market information
T_5: delivery of Material A
T_6: delivery of Material B

P_0: available construction capacity
P_1: construction processing
P_2: demand report
P_3: material plan
P_4: available market information
P_5: useful market information
P_6: prepare for Material A
P_7: available Material A
P_8: prepare for Material B
P_9: available material B

Figure 3: Incorporating the Just-In-Time concept into construction logistics

With the first assumption, the process of supplier selection is now omitted. The required materials can also be manufactured long before a formal order reaches the supplier in case the second assumption is satisfied. Therefore, the bottlenecks as shown in Figure 2 are now resolved. The “transitions” and “places” as illustrated in Figure 3 are much less than those in Figure 2.

Information is transferred through T_1 from time to time, with those flows representing the information being provided by the Planning Department regarding the construction process. The inventory information is also transmitted to the Planning Department and suppliers by firing T_1. To execute the function of T_1, a centralized information system can be maintained to gather and disseminate any information related to the construction process and material inventory. At the same time, market information is sent to the Purchasing Department through T_3. An information system can also be used to deal with the market information and for placing orders. The suppliers can prepare for the material supply before the order arrives, and this can significantly reduce preparation time.

In Figure 3, $w(P_6, T_5)$ and $w(P_8\ T_6)$ exist to ensure the materials are delivered after the order is placed. That means the firing of the delivery (T_5 and T_6) requires (i) the information "token" from the Project Department to begin the required preparation work in advance; and (ii) the order "token" from the Purchasing Department to initiate production (assuming that there is some storage on site). While the initial numbers are 4 and 5 (as shown in Figures 2 and 3), the storage of materials is always higher than 2 and 1 respectively in the simulation - which can be regarded as the optimum storage on site. This allows the system to be extended beyond the ideal JIT concept to accommodate a reasonable amount of stock being located on site to satisfy the requirements of the work.

The process shown in the improved JIT model requires a long and stable relationship between the construction company and its suppliers, as making information on project progress and material demand available to the suppliers is of paramount important to success. In practice, many construction companies already maintain a close relationship with their suppliers to enjoy the benefits of greater trade discount and efficient working relationships. The increased use of information technology such as Internet and Intranet, would also help ensure the necessary information is made available to the trade partners.

Conclusions

The often unpredictable nature of construction work often induces project managers to stock more materials on site than are actually required. This paper has presented one approach to managing this situation more successfully by means of a modified PN-JIT logistic system. By transferring information during the construction process, a contractor's Planning Department and suppliers would have improved knowledge concerning material on site and construction progress. Through the simulation model, it is apparent that the Planning Department can prepare a plan and transfer it to the Purchasing Department before a material shortage can occur. However, one precondition is that a long and stable relationship between the construction company and material suppliers must exist. The success of a good logistics system also relies on good communications among relevant parties. Since there are many analytical techniques related to PN, such as Colored PN (CPN), Stochastic PN (SPN), Generalized Stochastic PN (GSPN), an obvious next step of the research is to examine the practicality of applying some of those techniques in modeling and analyzing real construction logistics practice.

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